Indonesian Journal of Electrical Engineering and Computer Science
Vol. 15, No. 1, July 2019, pp. 258~265
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v15.i1.pp258-265

Performance comparison of micromachined antennas optimized at 5 GHz for RF energy harvester

Noor Hidayah Mohd Yunus[1], Jahariah Sampe[2], Jumril Yunas[3], Alipah Pawi[4], Mohd Izam Abd Jalil[5]
[1,2,3]Institute of Microengineering and Nanoelectronics, Universiti Kebangsaan Malaysia (IMEN-UKM), Malaysia
[1,4]Communication Technology Section, Universiti Kuala Lumpur-British Malaysian Institute (UniKL-BMI), Malaysia
[5]Electrical and Electronics Section, Universiti Kuala Lumpur-Malaysia France Institute (UniKL-MFI), Malaysia

Article Info

Article history:

Received Dec 15, 2018
Revised Feb 14, 2019
Accepted Feb 28, 2019

Keywords:

Borosilicate glass
Micromachining technique
RF energy harvesting
Sensor device
Silicon

ABSTRACT

This paper presents a comparative performance of the antennas fabricated using micromachining process. The research aims to discover the best antenna performance by alternative micromachining modes for integrating with the RF harvester printed circuit. Here, the study on micromachining process method involves the simulation study of three different structures and materials, such as silicon (Si) with air gap, Si surface and glass surface based antenna. These antennas have been modelled and optimized operating at 5 GHz by CST-MWS. The outcomes validate good characteristic of glass based surface micromachined antenna over the Si based micromachined antenna. The results show that the Si surface micromachined antenna is not able to reach the requirement for RF antenna specification, however, it is improved by creating the air cavity. Furthermore, the use of glass substrate has increased the antenna gain by 5.34% and the -10 dB bandwidth increased by 72.86% compared to the Si with air cavity. The glass based antenna dimension is reduced by 9.09% and 44.93% compared to Si bulk micromachined and Si surface micromachined antenna, respectively. Thus, the characteristics of the glass surface micromachined antenna are relatively appropriate for highly efficient RF energy harvester application.

Corresponding Author:

Noor Hidayah Mohd Yunus,
Communication Technology Section,
Universiti Kuala Lumpur British Malaysian Institute,
Batu 8, Jalan Sungai Pusu, 53100 Gombak, Selangor, Malaysia.
Email: noorhidayahm@unikl.edu.my

1. INTRODUCTION

Energy harvesting is a technique developed to enable fully autonomous powered sensors for battery-less device and wireless sensor network which may remove the limited dependability of standard chemical batteries used. Such sensors can be utilized in wearable devices, Internet of Things (IoT), structural health monitoring, remote control, etc [1-2]. Energy sources for energy harvesting system can be derived from solar, vibration, radio frequency (RF), motion, thermal and nearby electric field [1-7].

In this research, energy harvesting system from RF energy sources are focused since it is omnipresent in everywhere and at any time can provide extended support and lifespan to the devices. On an everyday basis, RF energy sources are consistently surrounded by mobile base station, cellular, transmission towers, television, Wi-Fi signals, radio broadcast stations, etc.

The RF energy harvesting system includes antenna, impedance matching circuit and power rectifying circuit. The general structure of the RF energy harvester is shown in Figure 1. In RF energy harvester, the RF signals are captured by the receiving antenna and converts to alternating current (AC) form. The impedance matching circuit composed of inductor and capacitor (LC) components, support for maximum power transferal into the rectifier. The rectifier converts AC voltage into direct current (DC) voltage for the desired application load. However, the typical RF power level source is too low as much as 1 μW/cm^2 for the energy harvesting [3]. Commonly, power supplies for the energy harvesting system and devices are driven by chemical batteries [6]. However, the battery has limited energy capacity, limited lifespan, required high maintenance, chemical leakages when unused and waste disposal in a long term period can bring environmental problems. Thus, RF energy harvested is suitable for green supply of low power consumption devices [8]. An efficient antenna of the RF energy harvester is highly essential for maximizing the RF signal reception.

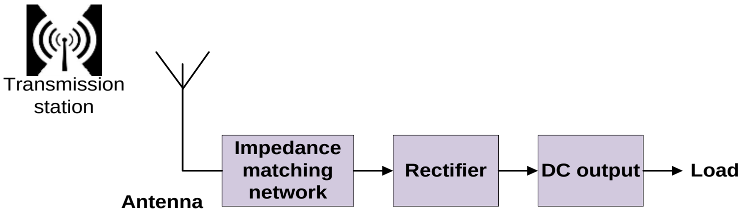


Figure 1. RF energy harvesting system

An antenna is a key important device in the front end of the RF energy harvester system since its affect the quantity of energy harvested [9]. Numerous recent research works have been reported on the antenna of the RF energy harvesting system to reach some device parameters, such as high efficiency [8, 10-12], lower return loss [2, 13-14] and good radiation pattern with high gain antenna [12, 14-15]. The current technology in RF energy harvester used conventional printed circuit board (PCB) substrate material such as Teflon, RT/Duroid and FR4, however, the mechanical structure stability of the materials is low owing to porous structural and low mechanical strength. Furthermore, the alteration of the materials are complex and required proper substance ratio division for designing pattern.

The standard methods found in a foundry were acceptable well the requirement to fabricate an antenna using a conventional substrate [16-19]. However, with these standard substrates, it is impossible to etch away by dry (or involving ionized gas or plasma) and wet (or chemical) etching. Hence the substrate thickness cannot be tuned and impossible to get flexible functionality to lower the dielectric permittivity. On the other hand, the micromachining technique in micro-electromechanical systems (MEMS) technology has shown its potential role for power efficient sensors and has contributed to the improvement of various RF antennas [10, 20-22].

The aim of this research stands not to compare numerous antenna designs but rather to compare the performance of the antenna using different substrate materials and structures that suitable for RF energy harvester operating at 5 GHz in unlicensed Industrial, Scientific and Medical (ISM) frequency band. This performance comparison is studied, illustrated by the simulation micromachining modes of bulk micromachining on crystal Silicon (Si) substrate as well as surface micromachining on crystal Si and glass substrate. Bulk micromachining involves selectively etch of Si substrate to produce an air cavity (dielectric permittivity, ε_r = 1) of the Si in a definite thickness ratio to get desired lower ε_r [15, 21]. Surface micromachining is characterized by the thin metal deposition by an appropriate thickness ratio of the pattern dimensional structure over a substrate surface [20, 22].

The crystalline structure and high mechanical stability of Si and glass substrate, respectively could allow the fabrication of MEMS device by micromachining technique for achieving appropriate RF device specification [13, 20]. In this research, the simulation results of the antennas using two micromachining methods are discussed in the following section. Lastly, concluding remarks is presented.

2. RESEARCH METHOD

2.1. Antenna Design

The previous work in [15] presented that a Si based micromachined antenna fabricated by bulk micromachining method provides improvement in terms of realized gain, radiation pattern, -10 dB bandwidth and the physical size reduction. Here, this research carries out on the comparison performance between the bulk micromachined antenna by Si substrate and surface micromachined antenna by two different substrate which are Si and glass. For simulations, investigation of the substrate used which are crystal Si (ε_r = 11.9, electrical conductivity of 0.00025 S/m) and borosilicate glass (ε_r = 4.7, tan σ = 0.0037 S/m) have been considered. The thicknesses tsub are 525 μm ± 25 μm and 2 mm for Si and glass, respectively. A 1 μm aluminium (A*l*) thickness with electrical conductivity = 3.56 x 10^{-7} S/m is structured as the metallization layer for the patch and the ground in which mounted on both sides of the antenna substrate. Metallization of copper also possible to be structured in which to moderate metal losses. All these dimensions are presented in Table 1. The antennas are modelled and optimized by Computer Simulation Technology Microwave Studio software (CST- MWS).

The top view layout and three-dimensional (3D) model of the rectangular radiator patch antenna are shown in Figure 2. The patch antenna layout for each type are the same while the geometric dimension is optimized to meet the 5 GHz operating frequency of the antenna. The low profile rectangular patch design allows to be easily mounted on a flat substrate. The patch antenna length l is usually from a 0.333 to 0.5 wavelengths of the substrate. The value can be obtained by equation from the transmission line model in which related with resonant frequency dominant TM mode [2, 23]. The model offers good physical insight, but less precise as the approximate calculation formula of antenna dimension is used. Optimization of the antenna by resonant properties in return loss parameter grid is performed by adjusting the dimension values using parametric sweep in CST-MWS.

$$f_r = \frac{1}{2(\ell + \Delta\ell)\sqrt{\varepsilon_{reff}}\sqrt{\mu_o \varepsilon_0}} \tag{1}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{t}{w}\right]^{-1/2} \tag{2}$$

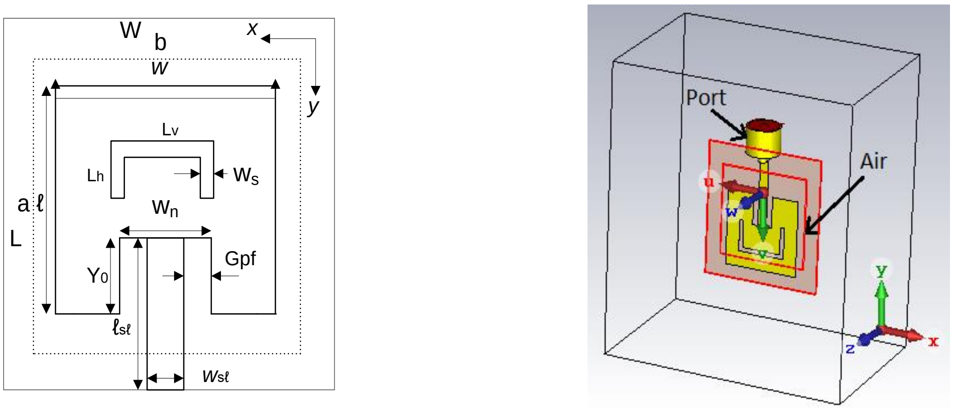
$$Z_{in} = Z_{\max} \cos^2\left(y_0 \frac{\pi}{\ell}\right) \tag{3}$$

where: l = Patch length
w = Patch width
ε_r = Dielectric permittivity
ε_{reff} = Effective dielectric permittivity
t = Substrate thickness
Z_{max} = Impedance at $y_0 = 0$

The antenna is characterized to have a 50 Ω input impedance. It is reformed by selecting the right position of the feeding point y_0 [23].

Table 1. Optimized Dimension of Micromachined Antennas Operating at 5 GHz

Dimension (mm)	L	W	***l***	***w***	a	b	**t_{air}**
Si surface	49	40	39.5	33	0	0	0
Si with air gap	30	27	17	17	20.46	20.46	0.375
Glass surface	25.06	26.5	16.11	20.48	0	0	0



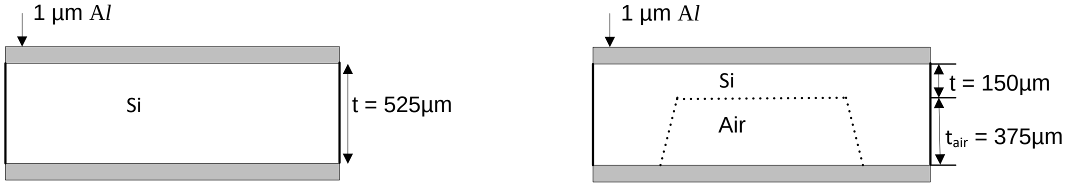
(a) (b)

Figure 2. Antenna design. (a) Geometry layout and (b) 3D model

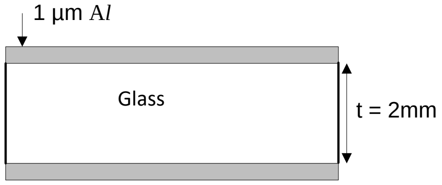
Optimum performance of the antenna depends on the ε_r and thicknesses of the substrate, feedline dimension (l_{sl}, W_{sl}), metal conductivity and the method used in fabrication that contribute to reduce the dielectric constant of the substrate. Here, micromachining technology is selected as it offers small tolerances, reliable and favourable manufacturing costs [24]. Descriptions of fabrication by micromachining method of the antennas are described in the following sub section.

2.2. Micromachining Method

Micromachining is presented as the key technology in MEMS systems. The cross section of the materials used in this micromachining is illustrated in Figure 3. This section presents two common micromachining methods for Si and glass which are semiconducting and insulating materials, respectively.



(a) Si surface (b) Si with air gap



(c)Glass surface

Figure 3. Cross-section of the material structures used for micromachined antennas

2.2.1 Bulk Micromachining

The factor of substrate thickness and dielectric permittivity substrates consideration might possibly influence on the performance of the antennas has been researched in [15, 21, 24]. Since the high ε_r of Si, a patch antenna requires an appropriate thin substrate thickness. Although a thick antenna substrate improves the bandwidth, but it excites surface waves in which influence for a poor radiation pattern and low efficiency. These matters can be achieved by using bulk micromachining process in which to etch away a Si substrate portion to create an air cavity or an air gap as shown in Figure 3(b).

Here the bottom lateral of 525 µm thick Si is anisotropically etched by 375 µm thick in 20.46 x 20.46 mm dimension. It involves wet etching in an anisotropic etching by Potassium Hydroxide (KOH) chemical etchant liquid. The chemically etched bulk Si results in an air cavity at the bottom lateral of the Si substrate. While the top lateral is metallized by sputtering a 1 µm A*l*. Patterning geometric layout of the patch antenna on the top lateral involves a photolithography process. Ground plane at the bottom lateral of the antenna substrate is performed by attaching adhesive solid of 1 µm A*l* sheet where the dimension is similar as the Si substrate size, 30 x 27 mm.

2.2.2 Surface Micromachining

In manufacturing, surface micromachining method is based on the planar process steps used continually to produce integrated electronic devices. To make extraordinary electronic systems, this developed planar process possibly be extended to engineering structures that require other than electronic devices which usually mechanical devices [22]. Surface micromachining is the process to deposit thin film on the surface of the substrate to form the mechanical parts. Si either monocrystal or polycrystal is the familiar functioning material for standard micromachining techniques [25].

Besides Si substrate, the glass substrate is also examined using this surface micromachining method, as shown in Figure 3(a) and 3(c). Here, both Si and glass substrates are metallized to make the radiator patch by sputtering a 1 µm Al on the top laterals. The geometric pattern of the radiator patch involves a photolithography process. While the bottom lateral of the both antennas substrates or the ground planes are created by sputtering a 1 µm A*l*. The dimension of the A*l* sputtered on the both Si and glass substrate are 49 x 40 mm and 25.06 x 26.5 mm, respectively.

3. RESULTS AND ANALYSIS

These three micromachined antennas are modelled to have a fed by 50 Ω input impedance characteristic. The operating frequency of the antennas is optimized at 5 GHz. The obtained simulation results of 5 GHz operating frequency is plotted in the return losses chart as in Figure 4. It is observed that the return loss (S11) is less than -10 dB (< -10 dB) except for Si surface micromachined antenna in which the parameter is above a level of -10 dB. Return loss S11 and voltage standing wave ratio (VSWR) parameters are important to determine the -10 dB bandwidth. The antenna bandwidth is performed based on < -10 dB return loss and VSWR value less than 2 (<2). From the simulation, Si bulk and glass surface micromachined antenna performed with VSWR value <2. Accordingly, no valuation of -10 dB antenna bandwidth and the VSWR value is more than 2 for Si surface micromachined antenna that corresponds to a major loss power owing to mismatch in the impedance line.

In ISM band, the acceptable bandwidth parameter that need to be achieved is as wide as from 100 MHz to 2.45 GHz. By comparing these micromachined antennas, it is found that wider -10 dB bandwidth (117 MHz, from 5.0644 to 4.9474 GHz) is seen in the glass surface micromachined antenna than (32 MHz, from 4.981 to 5.013 GHz) of the Si bulk micromachined antenna. Since the glass surface micromachined antenna has been engaged within the wide frequency range, it represents either the glass surface micromachined antenna could suitably radiate or receive the energy.

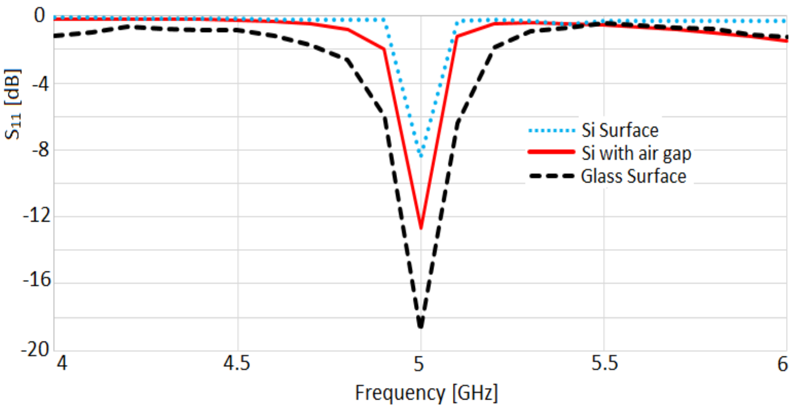


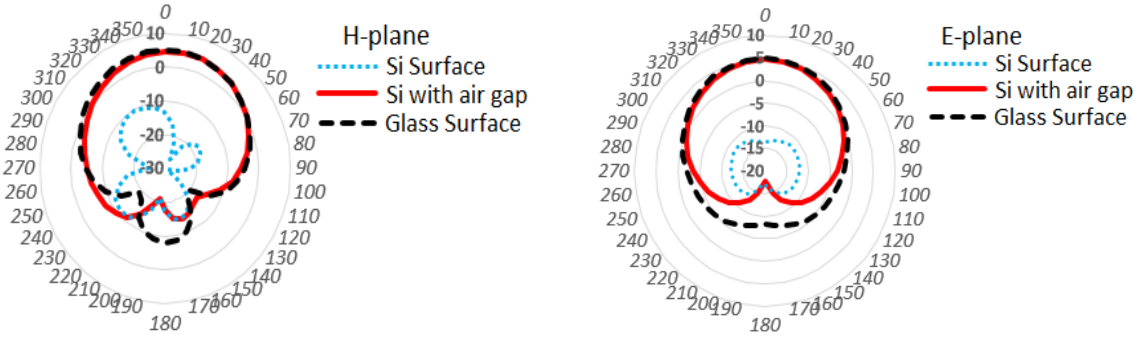
Figure 4. Return loss comparison optimized at 5 GHz

The simulated far-field radiation patterns in 2D planes of the micromachined antennas optimized at 5 GHz are shown in Figure 5. The antennas exhibit symmetrical and linearly omnidirectional beam in E-plane while non-homogeneous radiation pattern of Si surface micromachined antenna as well as an omnidirectional beam on the glass surface and Si bulk micromachined antennas in H-plane. Both of E and H planes of the micromachined antennas have a poor front-back ratio in terms of the radiation, thus, the antennas can be recognized for the radiation from the radiator patch.

Simulated peak gain and the directivity of the glass surface micromachined antenna are 5.022 dB and 3.81 dBi, respectively. For this antenna result, it is considered a high gain parameter of more than 5 dB (> 5 dB) and good directivity parameter in a static position to deliberate the radiation beam in the desired direction. The high gain and the directivity are desired for the antenna to capture and radiate more energy in all angles. However, the directivity of Si bulk micromachined antenna is higher as much as 0.544 dBi compared to glass surface micromachined antenna. It is illustrated that the Si bulk micromachined antenna is more effective to focus energy in a precise direction when receive the energy from a certain direction in a static position. Comparison of the simulation results obtained are tabulated in Table 2.

Table 2. Summary of simulated parameter characteristics operating at 5 GHz

Micromachined antenna	S_{11} (dB)	VSWR	-10 dB bandwidth (MHz)	Realized gain (dB)	Directivity (dBi)	Angular width (3 dB)	Pmax (W/m^2), r = 1m
Si surface	-8.45	22	n/a	-7.8	3.628	307	-19
Si with air gap	-12.7	1.6	32	4.754	4.354	100	0.238
Glass surface	-18.8	1.2	117	5.022	3.81	95.2	0.253



(a) H-field (x-z plane) (b) E-field (*y-z* plane)

Figure 5. Far-field radiation patterns

4. CONCLUSION

A comparison between three micromachined antennas are performed in order to find an appropriate design for integrated antenna which is well suited for the RF energy harvester application. System operating at 5 GHz in the microwave frequency band ranging from 0.3 to 30 GHz offers the possibility of individual device integration in the layout. Antenna parameters such as dielectric permittivity, dielectric thickness, conductivity metal, physical design and dimension of patch and substrate should be evaluated to recognize the effect on over-all antenna performance. The implication of the micromachined antenna modes has also given significant improvement by lowering the dielectric permittivity of the substrate material, bandwidth enhancement and realized gain. The results obtained point out the advantage of the glass surface micromachined antenna over the Si bulk and Si surface micromachined antennas in terms of the radiation gain, -10 dB bandwidth and VSWR parameter improvement. The glass surface micromachined antenna is found as a good candidate for integrating with RF energy harvester circuitry and its moderate physical dimension size also suitable for future integrated wireless devices by RF energy harvesting source.

ACKNOWLEDGEMENTS

The authors acknowledge the grateful to Universiti Kebangsaan Malaysia (UKM) and Universiti Kuala Lumpur British Malaysian Institute (UniKL BMI) for providing facilities, supporting this research financially and also guidance.

REFERENCES

[1] Yunus, N. H. M., Sampe, J., Yunas, J., & Pawi, A., “MEMS Based RF Energy Harvester for Battery-less Remote Control: A Review”, *American Journal of Applied Sciences*, vol. 14, no. 2, pp. 316-324, 2017.

[2] Yunus, N. H. M., Sampe, J., Yunas, J., & Pawi, A., *“Parameter Design of Microstrip Patch Antenna Operating at Dual Microwave-band for RF Energy Harvester Application”,* In 2017 IEEE Regional Symposium on Micro and Nanoelectronics, RSM 2017, pp. 92-95.

[3] Yildiz, F., “Potential Ambient Energy-Harvesting Sources and Techniques. Journal of technology Studies”, vol. 35, no.1, pp. 40-48, 2009.

[4] Sampe, J., Semsudin, N. A. A., Zulkifli, F. F., & Majlis, B. Y., ”Micro Hybrid Energy Harvester Circuit for Biomedical Application”, *Jurnal Kejuruteraan,* vol. 29, no. 1, pp. 41-48, 2017.

[5] Sampe, J., Zulkifli, F. F., Semsudin, N. A. A., Islam, M. S., & Majlis, B. Y., “Ultra Low Power Hybrid Micro Energy Harvester using RF, Thermal and Vibration for Biomedical Devices*”, International Journal of Pharmacy and Pharmaceutical Sciences,* vol. 8, no. 2, pp. 18-21, 2016.

[6] Yunus, M., Hidayah, N., Yunas, J., Pawi, A., Rhazali, Z. A., & Sampe, J., “Investigation of Micromachined Antenna Substrates Operating at 5 GHz for RF Energy Harvesting Applications”, *Micromachines*, *10*(2), 146, 2019.

[7] Sampe J, Yunus NH, Yunas J, Pawi A, Rhazali ZA. Design and fabrication of a dual band 1.8/2.5 GHZ antenna for RF energy harvester. *International Journal of Engineering & Technology.* 2018;7(4):3574-8.

[8] Fowler, C., & Zhou, J., “A Highly Efficient Polarization-Independent Metamaterial-Based RF Energy-Harvesting Rectenna for Low-Power Applications”, 2017.

[9] Sampe, J., Yunus, N. H. M., Yunas, J., & Pawi, A., “Ultra-low Power RF Energy Harvesting of 1.9 GHz & 2.45 GHz Narrow-band Rectenna for Battery-less Remote Control”, *International Journal of Information and Electronics Engineering,* vol. 7, no. 3, pp. 118-122, 2017.

[10] Quero, J. M., Perdigones, F., & Aracil, C., "Microfabrication Technologies used for Creating Smart Devices for Industrial Applications", *In Smart Sensors and MEMs (Second Edition)*, pp. 291-311, 2018.

[11] Shi, Yanyan, Yue Fan, Jianwei Jing, Lan Yang, Yan Li, and Meng Wang. "An Efficient Fractal Rectenna for RF Energy Harvest at 2.45 GHz ISM Band", *International Journal of RF and Microwave Computer-Aided Engineering*: e21424, 2018.

[12] Masius, A. A., Wong, Y. C., & Lau, K. T., "Miniature High Gain Slot-fed Rectangular Dielectric Resonator Antenna for IoT RF Energy Harvesting", *AEU-International Journal of Electronics and Communications*, vol. 85, pp. 39-46, 2018.

[13] Hyeon, I. J., & Baek, C. W., "Millimeter-Wave Substrate Integrated Waveguide Using Micromachined Tungsten-Coated Through Glass Silicon Via Structures", *Micromachines*, vol. 9, no. 4, 172, 2018.

[14] Agrawal, S., Gupta, R. D., Parihar, M. S., & Kondekar, P. N., "A Wideband High Gain Dielectric Resonator Antenna for RF Energy Harvesting Application", *AEU-International Journal of Electronics and Communications*, vol. 78, pp. 24-31, 2017.

[15] Yunus, N. H. M., Sampe, J., Yunas, J., & Pawi, A., *"Comparative Study of Si Based Micromachined Patch Antenna Operating at 5 GHz for RF Energy Harvester",* Proceedings of 2018 IEEE International Conference on Semiconductor Electronics, ICSE2018, Kuala Lumpur, 15-17 August 2018.

[16] Muhajir Mustapa, ZahrilAdha Zakaria, Noor Azwan Shairi, "Design of Quasi-Elliptic Bandpass Filter for Substrate Integrated Waveguide (SIW) Using Cross Coupling Technique*", Indonesian Journal of Electrical Engineering and Computer Science,* Vol. 12, No. 3, December 2018, pp. 1366-1372.

[17] Chiu, Yi, and Hao-Chiao Hong. "Rigid-Flex PCB Technology with Embedded Fluidic Cavities and Its Application in Electromagnetic Energy Harvesters." *Micromachines* 9, no. 6 (2018): 308.

[18] Hamzah, Azrul, Jumril Yunas, Burhanuddin Majlis, and Ibrahim Ahmad. "Sputtered encapsulation as wafer level packaging for isolatable MEMS devices: A technique demonstrated on a capacitive accelerometer." *Sensors* 8, no. 11 (2008): 7438-7452.

[19] Lei, Hongjie, Quan Wen, Fan Yu, Ying Zhou, and Zhiyu Wen. "FR4-based electromagnetic scanning micromirror integrated with angle sensor." *Micromachines* 9, no. 5 (2018): 214.

[20] Gkouzou, A., Kokorian, J., Janssen, G. C. A. M., & Van Spengen, W. M., "Friction and Dynamically Dissipated Energy Dependence on Temperature in Polycrystalline Silicon MEMS Devices", *Microsystem Technologies*, vol. 24, no. 4, pp. 1899-1907, 2018.

[21] Papapolymerou, I., Drayton, R. F., & Katehi, L. P., "Micromachined Patch Antennas", *IEEE Transactions on Antennas and Propagation*, vol. 46, no. 2, pp. 275-283, 1998.

[22] Bustillo, J. M., Howe, R. T., & Muller, R. S., *"Surface Micromachining for Microelectromechanical Systems",* Proceedings of the IEEE, vol. 86, no. 8, pp. 1552-1574, 1998.

[23] Garg, R., Bhartia, P., Bahl, I., Ittipiboon, A., "Microstrip Antenna Design Handbook", Artech House, 2001.

[24] Hasch, J., Haghighi, T., Schöllhorn, C., & Kasper, E., "Patch Antenna on Micromachined Silicon", *In Silicon monolithic integrated circuits in RF systems*, pp. 29-32, September 2004.

[25] ECM, E. M., "Reference module in materials science and materials engineering", 2016.

BIOGRAPHIES OF AUTHORS

Noor Hidayah Mohd Yunus received the B.Eng (Hons.) in Electrical Engineering from Tun Hussein Onn University, Malaysia, in 2005, and M.Sc. degrees in Telecommunication and Information Engineering from University of MARA, Malaysia, in 2008. She is currently working toward a Ph.D degrees in Microengineering and Nanoelectronics at Universiti Kebangsaan Malaysia. She is on leave as a Lecturer in Universiti Kuala Lumpur, Malaysia. She has been a trainer and guiding University graduated students in their Industrial Skills Enhancement Programme for Digital Signal Processing course. Her research interests include signal processing, communication engineering, renewable energy and modeling RF MEMS systems. She received the best student paper award from 2018 IEEE International Conference on Semiconductor Electronics (ICSE 2018), the best paper award from 2018 International Conference on Engineering Technology (ENTEC 2018) and outstanding postgraduate project award from 2018 IEEE Electron Devices Malaysia Chapter. She was the inventor of patent in RF MEMS antenna design.

Jahariah Sampe received the B.Eng (Hons.), M.Eng and Ph.D in Electrical, Electronic and System Engineering, Computer and Communication Engineering and VLSI Design (Digital) Engineering, respectively from Universiti Kebangsaan Malaysia, in 1996, 2003 and 2009, respectively. She is currently a Research Fellow and Senior Lecturer at Universiti Kebangsaan Malaysia and has certified Professional Engineer. She has been involved in IEEE activity including reviewing IEEE International conference papers. She has authored and coauthored more than 50 technical conference and indexed journal papers. Her research interests are in VLSI design, digital and and analog circuit, Energy harvesting (alternative resources), wireless and data communication and electronic and electrical field. She also the inventor of patent in RF MEMS design applications.

Jumril Yunas received the Bachelor and Master in Electrical Engineering from RWTH Aachen University, Germany, in 1988-1996, and Ph.D degrees in MEMS and Nanoelectronics from Universiti Kebangsaan Malaysia, in 2008. He is currently a Research Fellow and Associate Professor at Universiti Kebangsaan Malaysia, Malaysia. His research interests are in MEMS/NEMS technology, lab on chip, micro sensor, RF devices, power electronics and optoelectronic devices. He was the inventor of many patents including stack bonded on chip microtransformer, electromagnetic micropump and RF MEMS system design.

Alipah Pawi received the Bsc. in Electrical Engineering from Universiti Teknologi Malaysia, in 2000, and Msc in Personal Mobile & Satellite Communication from University of Bradford, UK, in 2002, and Ph.D in Digital Signal Processing from Brunel University, UK, in 2011. She is currently working as a Senior Lecturer at Universiti Kuala Lumpur. She has been a trainer and guiding University graduated students in their Industrial Skills Enhancement Programme for Digital Signal Processing course. Her research interests are in Digital Signal Processing and mobile communication engineering.

Mohd Izam Abd Jalil received the Diploma in Electrical Equipment & Installation Technology from Universiti Kuala Lumpur Malaysian France Institute, Malaysia in 2000, Professional Degree in Electrical & Electronic (Conduct Project) from University of Nice Sophia Antipolis, France in 2004, and Master of Engineering Technology in Electrical and Electronic, from Universiti Kuala Lumpur British Malaysian Institute, Malaysia in 2014. He is currently working toward Ph.D degress in Electrical Engineering specilization in Rail Transit Electrification and Information Technology at Southwest Jiaotong University, Sichuan, Chengdu, China. He is a lecturer in Universiti Kuala Lumpur, Malaysia and currently on study leave. His research interests include analog and digital circuit design, energy harvesting and electrical and electronics field.